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SUMMARY

The main task in the reported period has been the preparation of the tools for a non-dimensional sensitivity analysis. This sensitivity analysis will allow to generalize the results obtained so far in previous phases of our research and to perform a parametric investigation.

INTRODUCTION

The work on the task of non-dimensional sensitivity analysis started in November 1990 in parallel with the preparation of the report on the last year's activities. The progress of the work has been slower than expected for two separate reasons: the need to introduce and train new research personnel and the perturbations caused by the Gulf War.

At present, we are in the last phases of preparing and validating the computational tools for the parametric investigation.

This Interim Report describes two topics:

a. The principles of the planned non-dimensional sensitivity analysis.

b. The practical steps taken in preparing and validating the computational tools for the practical investigation.

NON-DIMENSIONAL ANALYSIS

In order to generalize the numerical results of any study, it is a common practice to express them in a proper non-dimensional form. In order to do so the following steps have to be taken: Scaling of **all** variables of the problem, based on a judicious selection of scaling parameters of some physical significance. Definition of the "similarity parameters" of the problem.

The present investigation effort has been guided by some well-known results of "linearized missile guidance" analysis and their extension as reported in Refs. 1 and 2.

Since the study involves point-mass models only the last two of the three basic dimensions (mass, distance and time) have to be scaled. In our dynamic model the missile is assumed to have a first-order transfer function with the time-constant τ_p. The value of this time-constant is selected therefore as the unit of "normalized" time.

$$\bar{t} = t/(t)_{ref} \tag{1}$$

$$(t)_{ref} = \tau_p \tag{2}$$

The unit of "normalized" distance was selected, based on the fact that the study is concerned with maneuvering targets, as a product for maximum lateral acceleration of the evader $(a_E)_{max}$ and τ_p^2. (In the "classical" linear guidance analysis, miss distances due to target maneuver are proportional to this factor.)

$$\bar{x} = x/x_{(ref)} \tag{3}$$

$$(x)_{ref} = \tau_p^2 (a_E)_{max} \tag{4}$$

Using the above defined scaling transformation keeps the following non-dimensional variables unchanged:

a. The pursuer-evader speed ratio (β)

$$\beta \triangleq \frac{V_P}{V_E} = \frac{\bar{V}_P}{\bar{V}_E} \tag{5}$$

b. The pursuer-evader maximum maneuver ratio (μ)

$$\mu \triangleq \frac{(a_P)_{max}}{(a_E)_{max}} = \frac{(\bar{a}_P)_{max}}{(a_E)_{max}} \tag{6}$$

c. The normalized time of flight (θ_f)

$$\theta_f \triangleq \frac{t_f}{(t)_{ref}} = \frac{R_o}{V_c} \frac{1}{\tau_p} = \frac{\bar{R}_o}{\bar{V}_c} \tag{7}$$

d. The "dynamic similarity parameter" (Refs. 1,2) defined by

$$\gamma^* \triangleq \frac{(V_E)_{max}}{V_E} \tau_p = \frac{(\bar{a}_E)_{max}}{\bar{V}_E} \tag{8}$$

Using the time scale change given by (1) all frequencies are normalized

$$\bar{\omega} = \omega(t_{ref}) = \omega\tau_p \tag{9}$$

This scaling equally refers to the actually assumed periodical random phase maneuvers and electronic jinking as well as to the shaping filters modelling these stochastic processes. The spectral density of the white noise, used as the input of the shaping filter has to be also rescaled according to the units of the considered disturbance.

In our previous investigation three types of disturbances were considered:

1. The "glint" noise of the radar receiver, modelled as measurement noise.
2. The periodical random phase target maneuvers.
3. The "electronic jinking".

The last two were considered as "process noises". As a consequence, another important similarity parameter has to be identified: the ratio of the two process noises, (in other words the "normalized jinking" parameter)

$$(\bar{W})_{max} \triangleq (W)_{max}/\tau_p^2(a_E)_{max} \tag{10}$$

Moreover, the "glint", which is proportional to the physical size of the target aircraft, must be scaled as all the other variables. Since the dimension of the glint spectral density Φ_{gl} is $[m^2 sec]$, the normalized spectral density should be

$$\bar{\Phi}_{gl} = \Phi_{gl}/\tau_p^2(a_E)_{max} \tag{11}$$

Keeping all the above defined similarity parameters constant should lead, according to the theory, to the same normalized miss distance

$$\bar{M} \triangleq R(t_f)/\tau_p^2(a_E)_{max} \tag{12}$$

against the same evader strategy.

In order to guarantee the same operational efficiency, i.e. the same single shot kill probability, the lethality range of the missile's warhead has to be kept proportional to the expected miss distance. This can be done if the non-

dimensional warhead lethality parameter, defined as

$$R_\ell^* \triangleq R_\ell/\tau_p^2(a_E)_{max} \tag{13}$$

is kept constant.

In summary, we have a set of seven non-dimensional similarity parameters β, μ, γ^*, θ_f, $(\bar{W})_{max}$, $\bar{\phi}_{gl}$, R_ℓ^*, as a basis of a parametric sensitivity analysis. In theory, for the same set of these parameters similar non-dimensional results, expressing a large family of dimensional results, are to be expected.

The number of parameters being quite large it seems to be useful to keep some of them constant and to carry out the parametric sensitivity analysis by varying only a few.

For the planned sensitivity analysis the following parameters are going to be kept constant:

the speed ratio $\beta = V_P/V_e$

the dynamic similarity parameter $\gamma^* = \dfrac{\tau_p(a_E)_{max}}{V_E}$

the normalized flight time $\theta_f = \dfrac{R_o}{V_c}\dfrac{1}{\tau_p}$.

The remaining parameters μ, $(\bar{W})_{max}$, $\bar{\phi}_{gl}$, R_ℓ^*, belong to two different groups. For a given scaling transformation, based on τ_p and $(a_E)_{max}$, μ and R_ℓ^* can be considered as design parameters of the missile, while $(\bar{W})_{max}$ and $\bar{\phi}_{gl}$ are related to the evading aircraft. The last two both depend on the physical dimension of the aircraft and have to be varied together accordingly. They signify the relationship between disturbance created by the evader's maneuverability and the disturbance due to ECM or glint respectively.

Another important distinction between the two pairs of these parameters is that the first two (μ and R_ℓ^*) do not interact with the estimation process and therefore no change in the "optimal estimation" is expected with their variations. However, if the ratio of the different disturbances is changed it

most certainly will require a modification of the estimator.

In this way the sensitivity analysis will be separated in tow parts:

a. sensitivity of the guidance performance,

b. sensitivity of the estimation quality.

This separation will also allow to obtain the correlation between the estimation error and the miss distance.

IMPLEMENTATION ISSUES

There are two options to carry out the above outlined non-dimensional parametric investigation. The first one is to use the existing computer code which is written in dimensional form, by carefully adapting the input in a way that the required similarity is preserved. The second option is to rewrite the computer code in non-dimensional variables.

In both cases careful validation tests has to be carried out in order to gain confidence in the method of the analysis and the results. Validation for each case is via comparison to some existing dimensional data.

Presently we are engaged in work using the first option and have already discovered already several problems to be addressed. In parallel with the above effort a new non-dimensional computer code is being generated.

CONCLUDING REMARKS

In this interim report the analytical basis of a non-dimensional parametric sensitivity analysis is outlined and the two options to carry out the task are indicated. Presently, work is being done parallel for both options.

REFERENCES

1. Shinar, J. and Rotsztein, Y., "Non-Dimensional Similarity Parameters in Pursuit-Evasion Problems", TAE Report No. 336, April 1978.

2. Forte, I., Steinberg, A. and Shinar, J., "On the Effects of Nonlinear Kinematics in Optimal Evasion", Optimal Control Application and Methods, Vol. 4, No. 2, 1983, pp. 139-152.